

[54] RESPIRATION APPARATUS WITH FLOW
RESPONSIVE CONTROL VALVE

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[56]

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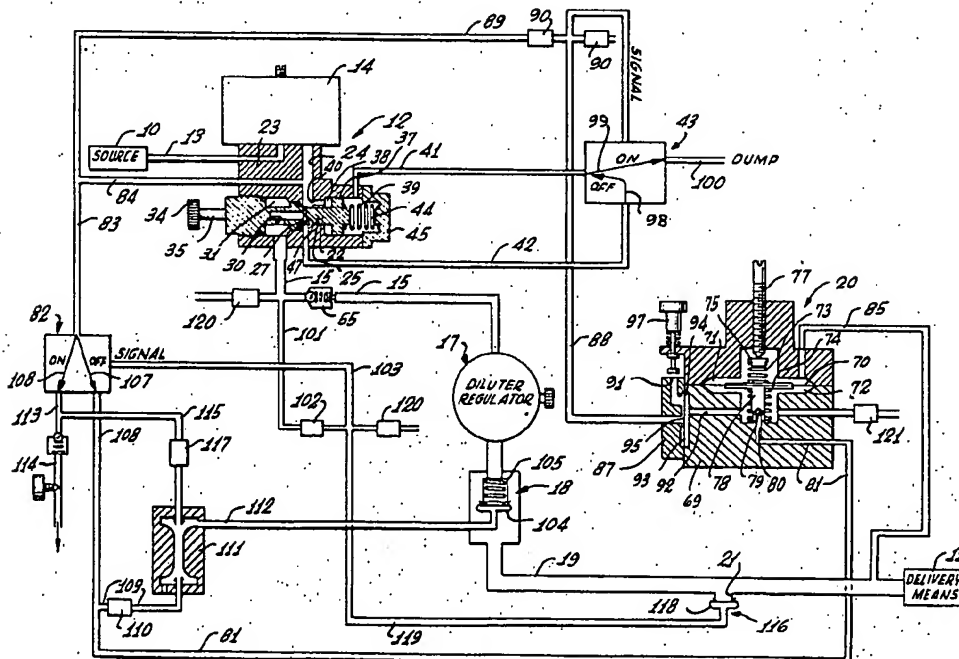
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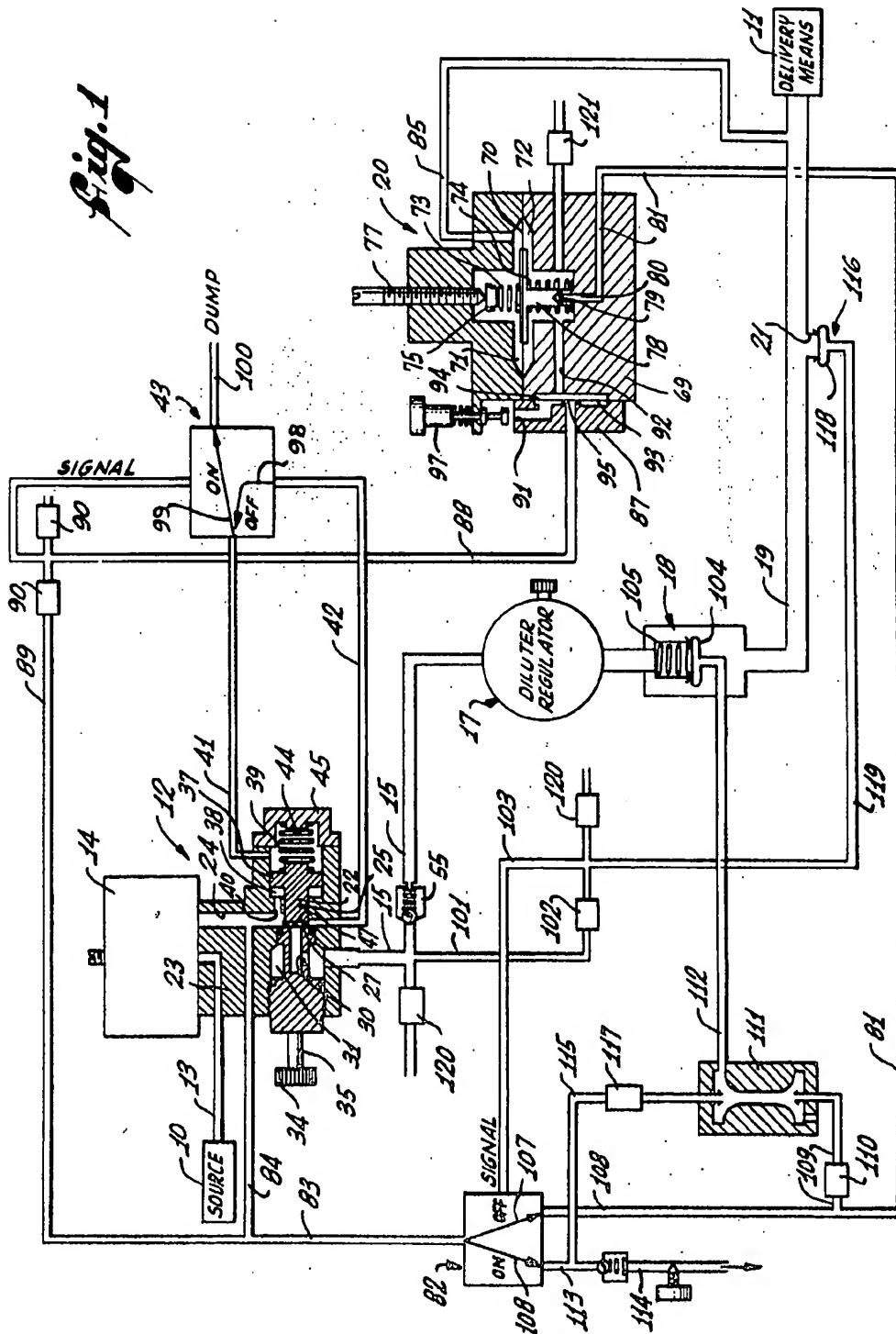
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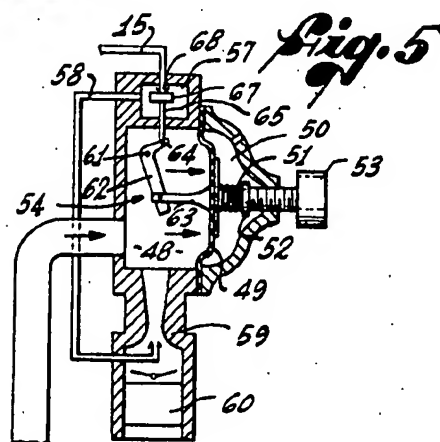
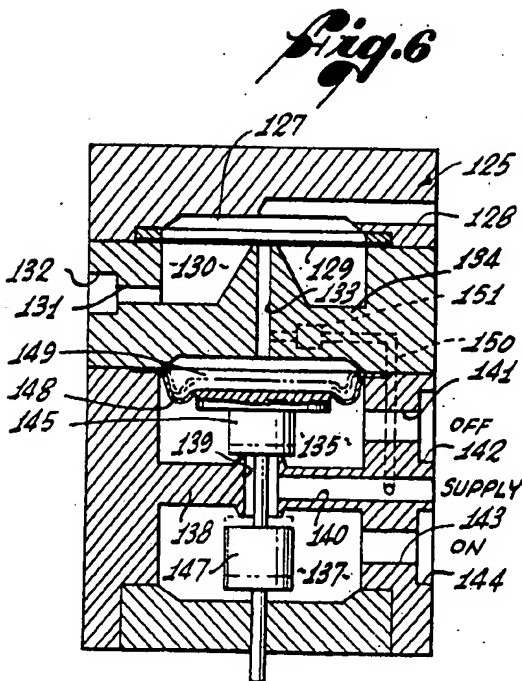
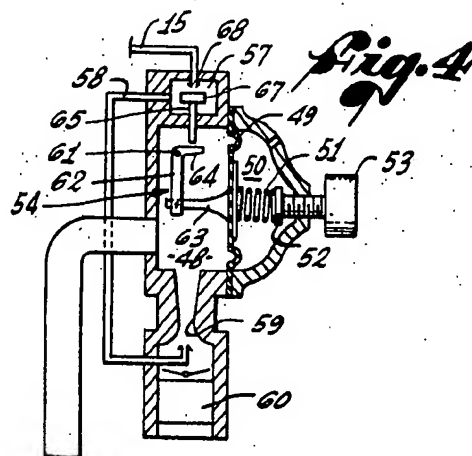
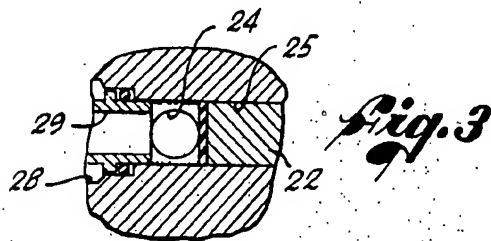
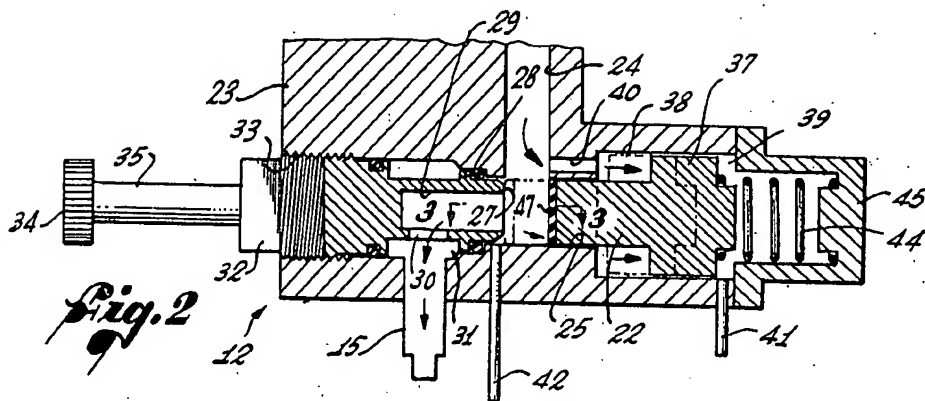
ABSTRACT

Intermittent positive pressure breathing apparatus having a combined flow-responsive and control valve which is opened to initiate the inspiration phase of a breathing cycle by a triggering valve, monitors the decreasing flow rate resulting from back-pressure buildup in the apparatus, and closes to terminate the flow at a selected and adjustable terminal flow rate. The control valve has a plunger that is carried by a piston upon which differential pressures are applied from the inlet and outlet ends of the valve's flow passage, and a spring assists the outlet pressure in urging the plunger toward an annular seat which is adjustably positioned on one side of the passage and defined as the beveled end of a tubular seat member. The plunger is positioned in the passage in accordance with the flow rate to maintain a constant pressure drop, and engages the seat to shut off all flow when the rate falls to the selected terminal flow rate.

7 Claims, 6 Drawing Figures







RESPIRATION APPARATUS WITH FLOW RESPONSIVE CONTROL VALVE

BACKGROUND OF THE INVENTION

This invention relates generally to respiration apparatus, and more particularly to an improved apparatus for intermittent positive pressure breathing (IPPB) therapy in which oxygen or oxygen-enriched air is supplied to a patient cyclically, under pressure, through delivery means such as a face mask or the like with a flow pattern which is similar to normal breathing. Such therapy can be used to provide life support during respiration failure, or to relieve respiratory distress from impaired breathing.

The cycles of an IPPB apparatus may be completely patient controlled, that is, initiated by slight inspiratory efforts by the patient, and also may be automatically controlled so that the apparatus initiates the breathing cycles at a timed rate if the patient does not breathe voluntarily. Each cycle begins with a peak flow which inflates the patient's lungs and then decreases to a relatively low terminal flow before the inspiration phase ceases. Following the inspiration phase, the lungs are vented to atmosphere during an expiration phase, which terminates when the next inspiratory effort of the patient initiates the next cycle.

An example of a highly effective IPPB system is that illustrated in U.S. Pat. No. 3,362,404, in which gas from a source is supplied at relatively high pressure (for example, 50 psi) to the delivery means through a flow-responsive valve, a pressure regulator, and a main flow valve which is opened and closed by pressure signals produced by the flow-responsive valve in response to changes in rate of flow through the flow-responsive valve. In this system, the inspiration phase is initiated by a triggering valve which substantially increases the flow through the flow-responsive valve in response to the initial inspiratory effort, and this increased flow opens a signal passage from the flow-responsive valve to the main valve to open the latter and admit the main flow from the flow-responsive valve to the patient. The flow-responsive valve closes the signal passage to close the main flow valve when the flow rate drops to a preselected and adjustable terminal level.

While the foregoing system has performed satisfactorily, it was designed for use with a high-pressure source of oxygen or air, often from a relatively noisy piston-type pump where there is no central supply system. Moreover, its cost is substantial in view of the fact that two major valves are required, one for flow-rate control and another on-off flow control, and the closing action of the main valve was controlled by the relatively slow bleeding of signal pressure from its actuating chamber.

SUMMARY OF THE INVENTION

The present invention resides in a respiration apparatus of the foregoing general character which has basically the same operating capabilities as the apparatus in the aforesaid patent, in which a single major valve performs the combined functions of both of the valves of the aforesaid apparatus, and which is capable of operation with a low-pressure source of oxygen or air. Accordingly, the apparatus is lower in cost and easier to assemble, and eliminates the need for an expensive and noisy pump for supplying high-pressure gas, permitting

the use of a less expensive and quieter rotary compressor.

More specifically, the respiration apparatus of the invention has a flow control valve including a valve member that is movable back and forth across a flow passage between open and closed positions, a sensing or triggering valve that is operable in response to an inspiratory effort by the patient to cause the opening of the valve member for the initial peak flow, and a pressure-responsive actuator for the valve member for variably positioning it in the passage in accordance with the flow rate by maintaining a substantially constant pressure drop between the inlet and outlet ends of the passage. As the flow rate is reduced during the build-up of system back pressure resulting from the inflation of the patient's lungs, the valve member monitors the decrease and is shifted correspondingly closer to the closed position to correspondingly reduce the flow area through the valve. When the desired terminal flow rate is achieved, the valve member seats and closes with a positive, snap action, the seat being selectively adjustable for selection of a desired terminal flow rate.

In the illustrative embodiment, the flow-responsive control valve comprises a plunger that is guided in the valve body for sliding toward and away from a beveled annular seat on one side of the flow passage, and is carried by a piston that is disposed between two pressure chambers, one communicating with the inlet end of the passage to receive higher pressure gas which develops an opening force, and the other connected for communication with the outlet end of the passage to receive lower pressure gas (due to the pressure drop occasioned by the restriction produced by the valve member) and develop a closing force which is augmented by a light spring force that is selected to maintain the pressure drop. The inspiratory effort by the patient is applied as a pilot signal to the sensing valve, which actuates a pilot valve to momentarily vent the second chamber, permitting the inlet pressure to throw the plunger open for the peak flow, after which the force of outlet pressure is added to the spring force to urge the plunger toward the closed position.

As back pressure builds up, a basically conventional diluter/regulator progressively restricts the flow to the patient, and thus the flow through the valve passage, tending to correspondingly reduce the pressure drop that would occur through a restriction of given size, so that the outlet pressure tends to rise toward the inlet pressure. Accordingly, the plunger is shifted progressively toward its seat and variably positioned in the passage in relation to the flow rate, to maintain the pressure drop, and engages the seat with a snap action to shut off all flow to the patient at a flow rate that is selected by adjusting the position of the seat within the passage. Thus, a single valve performs both of the functions that formerly required two valves, serving both as a direct "on-off" valve and as a monitor which senses the flow rate to terminate flow at a selected terminal flow rate.

Other objects and advantages of the invention will be apparent from the following detailed description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view, partly in cross-section, of a respiration system embodying the novel features of the present invention;

FIG. 2 is an enlarged fragmentary cross-sectional view of parts of the flow-responsive control valve, shown in the open position for peak flow, with moved positions of parts indicated in broken lines;

FIG. 3 is a fragmentary cross-sectional view taken substantially along line 3—3 of FIG. 2;

FIG. 4 is an enlarged, fragmentary cross-sectional view schematically illustrating the fully open condition of the diluter/regulator;

FIG. 5 is a view similar to FIG. 4 illustrating a partially closed condition of the diluter/regulator resulting from increasing system back pressure as the patient's lungs are inflated; and

FIG. 6 is an enlarged cross-sectional view somewhat schematically illustrating the structure of one of the pressure-operated pilot valves of the apparatus.

DETAILED DESCRIPTION

As shown in the drawings for purposes of illustration, the invention is embodied in a respiration apparatus for IPPB therapy, as illustrated schematically in FIG. 1, for delivering an intermittent, controlled flow of pressurized gas, typically oxygen or air, from a source 10 such as a pump or a storage tank to a patient (not shown) through conventional delivery means 11. The delivery means may take various forms, for example, that of a face mask over the patient's mouth and nose, through which the patient receives gas during each inspiration phase of operation, and exhales during each expiration phase of operation.

In general, the apparatus comprises a flow control means 12 which receive gas from the source 10 through a conduit 13 and a pressure-regulator 14, and deliver an intermittent controlled flow of the gas to a main flow conduit 15 through which the gas is carried to a basically conventional diluter/regulator 17 in which air may be mixed in the gas and back pressure building up in the system results in restriction of the flow from the flow control means 12. From the diluter/regulator, the gas (or gas mixture) passes through a check valve 18 and a continuation 19 of the main flow conduit to the delivery means, and thus to the patient.

Each inspiration phase of operation normally is initiated by a sensing valve 20 which is responsive to a pressure drop in the main conduit 19 to produce a pressure signal for opening the flow control means 12, and termination of the inspiration phase is effected by the flow control means in response to a decrease of the flow rate to the patient to the level selected for the terminal flow. At the same time, the expiration phase is initiated by the flow control means by opening an expiration port 21 from the main conduit 19 so that the patient may exhale to atmosphere.

In accordance with the present invention, the flow control means 12, which heretofore has comprised a separate flow-responsive valve and a separate main flow-control valve, is a single valve assembly having one valve member 22 which not only opens to admit gas to the delivery conduits and closes to shut off the flow, but also operates during each inspiration phase to monitor the varying flow during inspiration and shut off the flow in response to achievement of a selected low terminal flow. In this valve, both the structure and the assembly operations are simplified by the elimination of the need for a separate flow-control valve, and thus are less expensive, and the system is readily adaptable for use with relatively low-pressure sources so that

there is no need for relatively high-pressure gas for proper operation, hereby making it practical to operate with a less expensive and quieter pump than the pumps that have been used in the past, in the absence of a suitable central supply system.

More specifically, as shown in FIGS. 1 and 2, the valve 12 comprises a housing 23 on which the pressure regulator 14 is mounted, to receive gas from the source 10 through the conduit 13 and deliver it to the valve at the proper operating pressure, for example, 10 psi. The housing defines a flow passage 24 with an upper, inlet end for receiving the gas from the regulator and a lower, outlet end from which the controlled intermittent flow is delivered to the conduit 15, and also is formed with a transverse bore 25 which intersects the flow passage near the lower end thereof, on the right-hand side as viewed in FIGS. 1, 2 and 3.

The valve member 22 is a plunger which is slidably guided in the bore 25 for back and forth movement in the housing 23, toward and away from a valve seat 27 adjacent the opposite side of the bore. This valve seat is the annular end of an elongated seat member that is sealed in a second bore 28 opening transversely into the left-hand side of the passage 24, as it is viewed in FIG. 1, coaxial with the bore 25, the seat member having a blind bore 29 in its right-hand end portion defining an internal passage that communicates through one or more radial ports 30 with an annular chamber 31 outside the member, the main flow conduit 15 being connected to this chamber to receive gas therefrom.

The left-hand end portion 32 of the seat member is fitted into the valve housing 23 in a threaded left-hand end portion 33 of the bore, for axial movement of the seat member upon turning of an externally accessible knob 34 on a shaft 35 projecting to the left from the threaded end portion. Such axial movement adjusts the position of the seat 27 in the flow passage 24 and relative to the left-hand side of the flow passage, as viewed in FIGS. 1, 2 and 3.

To move the valve plunger 22 back and forth relative to the passage 24, a piston 37 is mounted on the right end portion of the plunger and is slidably fitted in an enlargement of the bore to divide the enlargement into two pressure chambers 38 and 39 in which gas pressure develops forces acting to urge the piston, and thus the plunger, in opposite directions. The chamber 38 on the left side of the piston is pressurized from the inlet end portion of the flow passage 24, above the plunger, through a connecting conduit 40, and the chamber 39 on the right side of the piston is connected to a conduit 41 that is arranged to be pressurized from the outlet end portion of the flow passage, below the plunger, when the conduit 41 is connected to a conduit 42 through a pilot valve 43.

In addition to the closing force developed by gas in the chamber 39, a light coiled spring 44 is compressed between the piston and the right end wall 45 of the housing, thus adding a preselected closing force to the plunger, for example, a force of about one-half of 1 pound. Accordingly, when the gas-pressure forces are equal, the spring will hold the plunger 22 against the seat 27, but when the pressure develops an opening force greater than the combined force of the spring 44 and force exerted from the chamber 39, the plunger is moved to the right, away from the seat. A resilient end cap 47 on the end of the plunger engages, and seals against, the seat 27 when the valve is closed.

Moreover, when the plunger 22 is in an open position, the spring 44 urges it toward the closed position, and tends to restrict the size of the flow passage 24, so that a pressure drop is created between the inlet and outlet ends, related directly to the cross-sectional flow area through the restriction and to the rate of flow of gas through the restriction. Assuming an inlet pressure of 10 psi and a flow passage sized to produce a peak flow of from 100 to 120 liters per minute when the valve is fully open, a pressure drop of about one-quarter of 1 psi will be developed across the plunger. Accordingly, a pressure differential of about one-quarter of 1 psi will exist between the chambers 38 and 39.

This pressure drop would tend to decrease, however, as the flow rate past the plunger decreases, so that the closing pressure in the chamber 39 would tend to increase toward the opening pressure in the chamber 38. As this occurs, however, the spring 44 and the closing pressure cooperate to shift the plunger progressively to the left, increasing the degree of restriction of the flow passage to keep the pressure drop substantially the same.

As a result, the plunger 22 is variably positioned in the flow passage 24 in accordance with the flow rate through the passage to maintain a substantially constant pressure differential between the chambers 38 and 39, in accordance with the force exerted by the spring. The adjustable seat 27 can be set to be engaged by the plunger in different positions of the latter, and thus when different selected terminal flow rates are being delivered. It has been found that variations in the position of the seat within the passage have little, if any, effect on the response of the plunger to different flow rates, this being attributed, in part, to the fact that the end of the seat member is beveled toward the seat.

The diluter/regulator 17 may be a unit similar to units that have been sold in respiration apparatus for some time by Puritan-Bennett Corporation, Santa Monica, Calif., identified as the 0666 Diluter/Regulator. As shown schematically in FIGS. 4 and 5, such a unit has a main pressure chamber 48 containing gas at system pressure and defined in part by a diaphragm 49, the chamber 50 on the other side of the diaphragm being vented to atmosphere. The diaphragm is urged toward a normal, balanced position (FIG. 4) by a spring 51 having a seat 52 which is adjustable by a knob 53 to vary the spring force, thereby calibrating the unit for different pressure ranges, and the diaphragm is connected to a linkage 54 for variably restricting the flow through the device in response to system pressure changes which increase the pressure in the chamber 48 so as to move the diaphragm to the right in FIGS. 4 and 5.

Gas from the valve 12 is delivered to the diluter/regulator through a check valve 55 and the conduit 15, which opens into a flow chamber 57 from which a branch conduit 58 carries the gas to the chamber 48. If air is to be mixed with the gas to dilute it, this is accomplished by directing the gas through a venturi 59, to draw air in through a filter 60 and inject the resulting mixture into the chamber 48. From this chamber, the mixture passes out of the diluter/regulator to flow to the delivery means 11 through the check valve 18 and the conduit 19.

The linkage 54 is illustrated in FIGS. 4 and 5 by an L-shaped bell crank having a fixed pivot 61 in the

chamber 48, a first leg 62 depending from the pivot and joined to the diaphragm 49 by a connecting rod 63 extending between the lower end portion of the leg and the central portion of the diaphragm, and a second leg 64 projecting laterally from the pivot beneath the stem 65 of a plunger 67 that is slidable vertically in a partition separating the chambers 48 and 57. The head of this plunger is movable toward and away from an inlet orifice 68 which admits gas from the conduit 15 into the chamber 57, and thus through the branch conduit 58 into the chamber 48.

When the pressure in the chamber 48 is low, before the lungs of the patient are inflated, the linkage 54 and the diaphragm 49 are positioned as shown in FIG. 4 so as to leave the orifice 68 open and unrestricted for a full flow of gas through the diluter/regulator to the patient. As the patient's lungs become inflated and back pressure develops in the system, the diaphragm is shifted to the right, rocking the bell crank counterclockwise to raise the plunger and shift its head toward the orifice, through the position shown in FIG. 5, thereby restricting the flow through the system.

For example, when there is virtually no back pressure, the diluter/regulator may be set to deliver a full flow to the patient, and to reduce the flow rate first gradually as the back pressure begins to increase, and then more rapidly as the back pressure approaches a selected maximum, closing the orifice completely if that maximum (e.g., 40 centimeters of water) ever is developed in the chamber 48.

The illustrative sensing or triggering valve 20 (FIG. 1) for initiating each respiration cycle in response to an inspiratory effort of the patient is a pressure-operated pilot valve which is opened by the slight pressure drop in the conduit 19 resulting from the inspiratory effort, and then delivers a pressure signal to the pilot valve 43 to momentarily vent the spring chamber 39 of the valve 12. When this is done, the inlet-pressure force in the chamber 38 throws the plunger 22 to the fully open position to admit the peak flow through the flow passage 24 and into the delivery system.

As shown in FIG. 1, the sensing valve 20 comprises a main housing 69 in which a diaphragm 70 is centrally mounted to divide the hollow interior into two chambers 71 and 72, and the diaphragm is urged toward the centered position shown in FIG. 1 by opposed light springs 73 and 74, the spring 73 being compressed between the diaphragm and a seat 75 which is adjustably positioned by a threaded screw 77 to set the sensitivity of the sensing valve. A push rod 78 is carried by the diaphragm and normally presses a closure ball 79 into a closed position over a port 80 opening upwardly into the chamber 72 from a conduit 81 which normally is connected through a pilot valve 82 (left portion of FIG. 1) to a conduit 83. This conduit is pressurized with gas at inlet pressure (e.g., 10 psi) through a branch conduit 84 leading to the inlet end portion of the flow passage 24 of the valve 12.

To apply patient suction to the upper chamber 71 of the sensing valve 20, a conduit 85 extends between this chamber and the main delivery conduit 19 adjacent the delivery means 11. When the forces on the diaphragm are finely balanced, a very slight pressure drop in the upper chamber 71 is sufficient to cause the diaphragm to rise, first cracking open the port 80, and then being opened fully by the inlet pressure admitted into the lower chamber 72.

Mounted on the left-hand side of the housing 69 is a manifold 87 into which a conduit 88 normally delivers a continuing flow of low-pressure gas from another conduit 89 that communicates with the branch conduit 84 from the inlet end portion of the flow passage 24. A pair of restrictors 90 reduce the pressure in the conduit 88 to a suitably low level, such as one-quarter of 1 psi.

While the diaphragm 70 holds the high-pressure port 80 closed, the gas flowing into the manifold 87 simply escapes to atmosphere through a vent port 91 in the manifold. When the diaphragm 70 opens the high-pressure port 80, however, the resulting pressure increase in the lower chamber 72 is applied through a conduit 92 to a second flexible diaphragm 93 covering a chamber 94 formed in the left-hand side of the housing 69. This bulges the diaphragm 93 to the left to block an orifice 95 through which gas flows to the vent port 91, thus building up back pressure in the conduit 88. This back pressure build-up is the pressure signal for initiating operation of the valve 12, through the pilot valve 43. A manually operable plunger 97 is disposed over the vent port 91 so that a cycle may be initiated manually, if desired.

In this instance, the pilot valve 43 is a diaphragm-type valve which responds to the back-pressure signal to shift from an "off" condition to an "on" condition, both schematically illustrated in FIG. 1 by arrows 98 and 99, respectively, indicating the flows through the valve in the respective conditions. This connects the conduit 41, leading to the closing chamber 39, to a vent 100, rather than to the conduit 42 leading to the outlet end of the flow passage 24, and thereby relieves the relatively high pressure in the closing chamber 39 (due primarily to leakage around the piston 37). This permits the force developed in the opening chamber 38 to shift the piston and the plunger 22 from the closed position (FIG. 1) to the right to the open position (FIG. 2), and to initiate the flow through the valve 12 into the conduit 15 leading through the diluter/regulator 17 to the delivery means 11.

As gas begins to flow through the main conduit 15 to the diluter/regulator 17, signal pressure is transmitted through a conduit 101, a restrictor 102 and a conduit 103 to the pilot valve 82 for resetting the sensing valve 20 and opening the check valve 18 between the main conduits 15 and 19. This check valve is of the "mushroom" type, having an inflatable closure 104 which holds the initial negative or reduced pressure in the conduit 19 for operating the sensing valve 20, and includes a "fail safe" spring 105 for opening the check valve to pass air from the diluter/regulator to the delivery means if the pressure system ever should fail.

The pilot valve 82 is similar to the pilot valve 43, being actuated by signal pressure to shift from the "off" condition to the "on" condition, as shown schematically by the arrows 107 and 108 in FIG. 1. In the "off" condition, high pressure from the conduit 83 is applied through the pilot valve to a conduit 108 leading to the conduit 81 to the sensing valve port 80 and also flows through a branch conduit 109, a restrictor 110 and an operator 111 to a conduit 112 leading to the closure 104 of the check valve 18. This inflates the closure to close the check valve.

In the "on" condition, high pressure is removed from the sensing valve port 80, thereby permitting the diaphragm 70 to reseat the closure ball 79, and is shifted

to a conduit 113 which may have one branch 114 for operating a conventional nebulizer (not shown), and a second branch 115 leading to the check valve operator 111, through a restrictor 117. This second branch enters an upper, venturi-like portion of the operator so that the resulting flow of gas past the adjacent end of the conduit 112 reduces the pressure in the closure 104 to open the passage between the two main conduits 15 and 19. While this is occurring, the opening of the orifice 95 in the sensing valve manifold 87 terminates the back-pressure signal to the first pilot valve 43, returning it to the "off" condition in which conduits 41 and 42 communicate through the pilot valve, to transmit the outlet pressure from the passage 24 to the closing chamber 39.

The pilot valves 43 and 82 may take various conventional forms which respond to a pilot-pressure "input" signal to perform a switching function with respect to "supply" pressure, one suitable form being illustrated in FIG. 6. This pilot valve has a hollow body 125 with an upper actuating chamber 127 to signal conduit, such as the conduit 103, and has a flexible diaphragm 129 forming its lower wall so as to be urged downward when the chamber 127 is pressurized.

Below the diaphragm 129 is a second chamber 130 from which a passage 131 leads to a "dump" port 132, this chamber being arranged to receive gas through a central conduit 133 through the upper partition 134 forming the bottom wall of the chamber 130. The diaphragm 129 overlies the upper end of the central conduit 133, and covers this conduit to close it when the upper chamber 127 is pressurized.

Two additional chambers 135 and 137 are formed in the lower portion of the valve body 125 and are separated by a second partition 138. A connecting passage 139 is formed through the partition, and is supplied with pressurized gas through a branch passage 140. A passage 141 leads from the chamber 135 to an "off" port 142, and a passage 143 leads from the chamber 137 to an "on" port 144.

Mounted in the passage 139 is a shuttle-type closure member having two heads 145 and 147 above and below the partition. The upper head 145 is movably carried by a flexible diaphragm 148 forming the bottom wall of a chamber 149 beneath the upper partition 134 and communicating with the lower end of the central conduit 133, which also receives pressurized gas from the branch passage 140, through an internal passage 150 controlled by a flow restrictor 151.

With this arrangement, in the absence of signal pressure in the upper chamber 127, pressure in the central passage 133 is relieved through the chamber 130 and the "dump" passage 131, and supply pressure applied through the branch passage 140 pressurizes the chamber 135 to raise the shuttle and hold the lower head 147 over the lower end of the connecting passage 139, so that the valve delivers supply pressure through the branch passage 140 to the "off" port 142.

When signal pressure is applied to the upper chamber 127, the diaphragm 129 is pressed against, and closes, the upper end of the central passage 133, so that the chamber 149 is pressurized to shift the shuttle downward and cause the upper head 145 to block the upper end of the connecting passage 139. This switches the supply pressure in the branch passage 140 to the lower chamber 137, and thus connects the branch passage to

the "on" port 144, as long as signal pressure is maintained in the upper chamber 127.

Various porting arrangements are possible with valves of this type, to achieve the desired switching functions. This type of valve thus may be used for both of the valves 43 and 82.

The exhalation port 21 normally is closed by a check valve 116, herein having a "mushroom" closure 118 which is inflated during the inspiration phase but depressurized during the expiration phase. For this purpose, the inflatable closure is connected to a conduit which leads to the signal conduit 103 that is pressurized when gas begins to flow through the first main conduit 15, thereby inflating the closure 118 to close the port 21. When the flow of gas to the main conduit 15 is terminated by closing of the valve 12, pressure in the conduits 101, 103 and 119 is bled out through restrictors 120, and the closure is depressurized so as to open and release exhaled gas to atmosphere.

SUMMARY OF OPERATION

Although the manner of operation of the respiration system and apparatus will be apparent to those skilled in the art from the foregoing description of the main components and their functions, a summary of such operation may emphasize more clearly the features of the present invention. Assuming that the system is at rest with the elements in the conditions shown in FIG. 1, that oxygen at a supply pressure of 10 psi is available in the flow passage 24 of the main, flow-responsive valve 12, the two valve chambers 38 and 39 contain gas at substantially the same pressure so the spring 44 holds the plunger 22 in the closed position.

Ten psi pressure is supplied through the conduit 83 to the pilot valve 82, and through the "off" circuit of this valve, the check valve 18 is closed and 10 psi gas is available at the sensing valve port 80, which is closed by the diaphragm 70 and the closure ball 79. Similarly, 10 psi pressure is supplied to the conduit 89, and a signal flow is passed through the restrictor 90 and the conduit 88 to the manifold 87 to bleed through the orifice 95 and out through the vent 91.

When the delivery means 11 is applied to a patient, a slight inspiratory effort by the patient produces a pressure drop in the chamber 71 above the diaphragm 70 of the sensing valve 20, sufficient to raise the diaphragm and permit 10 psi gas to pressurize the lower chamber 72, thus pressing the diaphragm 93 against the orifice 95 to block the escape of gas from the conduit 88 and cause a back-pressure build-up therein. This actuates the pilot valve 43 to the "on" condition, connecting the conduit 41 to the vent 100 to relieve the pressure in the closing chamber 39, and the valve 12 is opened.

The ensuing flow of gas through the passage 24 is at the selected peak flow rate determined by the supply pressure and the effective flow area of the valve, and immediately supplies gas to the diluter/regulator while pressurizing the conduits 101, 103 and 119 to shift the pilot valve 82 to the "on" condition, terminate the supply of the 10 psi gas to the sensing valve port 80, open the inspiration check valve 18, and close the exhalation check valve 116. As the 10 psi pressure is relieved in the sensing valve chamber 72 through a bleed restrictor 121, the orifice 95 is unblocked and the pressure signal to the pilot valve 43 is terminated. Accordingly, this pilot valve is reset to the "off" condition in which the

conduits 41 and 42 communicate with each other through the pilot valve.

As the foregoing control functions are performed, the gas delivered by the valve 12 floods the main conduits 15 and 19, is diluted in the diluter/regulator 17, and flows through the delivery means 11 to the patient to begin inflating his lungs. During the initial portion of the inspiration phase, the peak flow rate is delivered by the valve and back pressure in the chamber 48 of the diluter/regulator is negligible, so the orifice 68 is unrestricted, as shown in FIG. 4.

As soon as the pilot valve 43 is reset, the pressure at the outlet end of the passage 24 is applied to the closing chamber 39 and its force is added to that of the spring 44, to oppose the force developed by inlet pressure in the opening chamber 38. With the relatively high peak flow rate that exists prior to build-up of any substantial back pressure, the desired pressure drop is produced while the plunger 22 is maintained in a relatively wide-open position. When the back pressure begins to build up, the diluter/regulator reduces the flow rate correspondingly, as illustrated in FIG. 5, and the reduced flow rate through the flow passage 24 results in movement of the plunger to the left to restrict the flow area and maintain the pressure drop, so that the position of the plunger continues to correspond to the flow rate.

The position of the seat 27 is adjusted initially, based upon an empirical determination of valve characteristics, so that the plunger 22 will engage the seat and terminate the flow of gas at the desired terminal flow rate. It has been found that the plunger closes with a snap action after it has come within a few thousandths of an inch of the seat, regardless of the particular position selected for the seat, and that the seat position has, at most, a negligible effect on the response of the plunger to changes in the flow rate.

When the plunger 22 shuts off the flow, the supply of gas to the patient ceases, the pressure in the conduits 101, 103 and 119 is bled out of through the restrictor 120, and the pilot valve 82 is therefore reset to close the check valve 18 as the pressure in the exhalation chamber 48 is relieved to permit the patient to exhale. The reduction in the pressure in the chamber 48 of the diluter/regulator restores the diaphragm 49 to the position shown in FIG. 4, and the system is ready to initiate another cycle in response to the next inspiratory effort by the patient.

From the foregoing, it will be apparent that the present invention provides an IPPB apparatus in which the flow-responsive monitoring function and the "on-off" flow control function are accomplished with a single valve that is relatively simple in construction and effective in construction, so as to achieve the same basic operating characteristics as the apparatus of the aforesaid patent, but with less expensive components, and with the performance advantages that result from direct control of the on-off function by the flow-responsive valve.

It also will be evident that, while a preferred form of the invention has been illustrated and described, various modifications and changes may be made without departing from the spirit and scope of the invention.

We claim:

1. In a respiration apparatus for administering intermittent positive pressure breathing therapy to a patient, and having delivery means for administering gas to the

patient, and conduit means for carrying the gas from a source to the delivery means, the combination of:

- a control valve having a flow passage with an inlet end for receiving gas from the source at a regulated, substantially constant input pressure, an outlet end, a tubular valve seat member adjustably mounted in said valve, said seat member having a beveled annular end along one side of said passage and terminating in an annular seat projecting varying distances into said passage in different adjusted positions of said seat member, the interior of said seat member communicating between said outlet end and said conduit means, and a plunger slidably mounted in said valve for movement toward and away from said seat, between open and closed positions;
- a piston carrying said plunger and slidably mounted in said valve, said valve having first and second pressure chambers on opposite sides of said piston, said first chamber communicating with said inlet end and arranged to apply force to said piston determined by inlet pressure, thereby to urge said plunger toward said open position;
- spring means urging said plunger toward said closed position with a preselected force;
- first and second signal conduits communicating respectively with said outlet end and with said second chamber, to apply the pressure in said outlet end to said second chamber when said signal conduits are connected, thereby urging said plunger toward said closed position;
- pilot valve means normally connecting said signal conduits and operable when actuated to vent said second chamber through said second signal conduit, thereby to permit the force of inlet pressure in said first chamber to shift said plunger to the open position;
- means communicating with said conduit means, responsive to a slight inspiratory effort at said delivery means and operable to actuate said pilot valve means momentarily, thereby initiating a flow of gas through said control valve;
- and means responsive to back pressure in said conduit means for restricting the flow rate as such back pressure increases during inflation of the patient, thereby reducing the flow rate past said plunger and causing the latter to move toward said seat and close against the latter when a preselected terminal flow, determined by the adjustment of said seat, is achieved, such closure terminating the delivery of gas from the source to said conduit means.

2. In a respiration apparatus for administering intermittent positive pressure breathing therapy to a patient, and having delivery means for administering gas to the patient, and conduit means for carrying the gas from a source to the delivery means, the combination of:

- a control valve having a flow passage with an inlet end for connection to the source and an outlet end connected to said conduit means to deliver gas thereto, a valve seat, and a valve member movable back and forth, toward and away from said seat between an open position and a closed position and operable to admit a peak flow from the source through said passage in said open position, to block flow from the source through said passage to said conduit means in said closed position; and to vari-

ably restrict said passage in intermediate positions;

pressure-responsive means for positioning said valve member in said passage in accordance with the flow rate to said delivery means and maintaining a substantially constant pressure drop across said valve member and between said inlet and outlet ends while gas is flowing through said passage, said pressure-responsive means including first means urging said valve member toward said open position with a first force determined by the pressure at said inlet end, second means urging said valve member toward said closed position with a second force determined by the pressure at said outlet end, and spring means for adding a preselected third force to said second force and variably positioning said valve member in said passage to maintain a preselected pressure drop across the valve member while gas is flowing through said passage, and normally holding said valve member in said closed position to prevent flow through said passage;

means actuated by an inspiratory effort of the patient at said delivery means for momentarily shifting said valve member out of the closed position to start flow to said conduit and delivery means at a selected peak flow rate;

and rate-control means in said conduit means responsive to the back pressure in said apparatus during inflation of the patient, and operable to restrict the flow rate as the back pressure builds up, whereby increasing back pressure results in a decreasing flow rate and a tendency to reduce said pressure drop, and said pressure-responsive means shifts said valve member toward said seat to maintain said pressure drop until said valve member engages said seat to terminate the flow, said seat being disposed along one side of said flow passage in a preselected position determined by the position of said valve member when the desired terminal flow rate occurs.

3. Respiration apparatus as defined in claim 2 further including means mounting said seat for selective adjustment across said passage, toward and away from the open position of said valve member, thereby to vary the flow rate at which said valve member engages said seat.

4. Respiration apparatus as defined in claim 3 in which said seat is the annular end of a tubular member, and in which the interior of said tubular member connects said passage to said conduit means and is blocked by engagement of said valve member with said end.

5. Respiration apparatus as defined in claim 4 in which said tubular member has a peripherally beveled end forming said seat.

6. Respiration apparatus as defined in claim 2 in which said pressure-responsive means comprise a piston connected to said valve member, a first chamber on one side of said piston communicating with said inlet end to form said first means, and a second chamber on the other side of said chamber connected for communication with said outlet end to form said second means.

7. Respiration apparatus as defined in claim 6 in which said means for momentarily shifting said valve member out of said closed position comprise a pressure-operated pilot valve operable when actuated, in response to patient suction, to vent said second chamber.

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